

FIG. 1

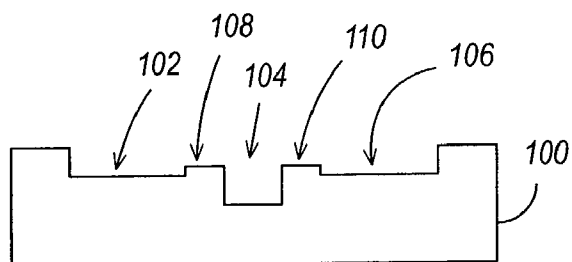


FIG. 2

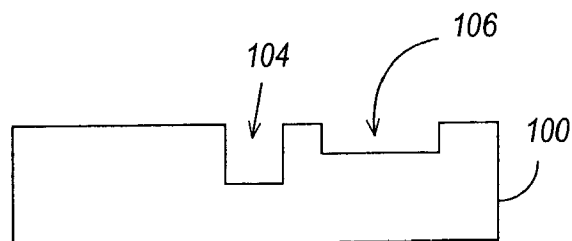


FIG. 3

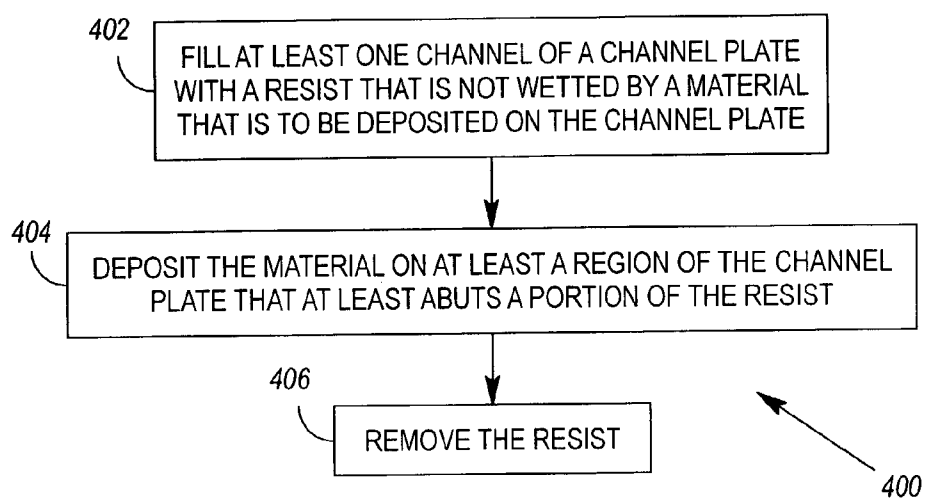


FIG. 4

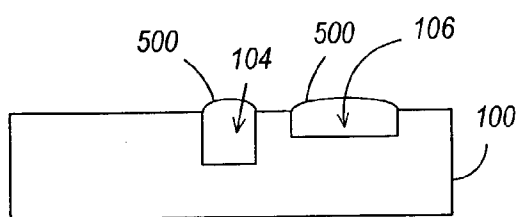


FIG. 5

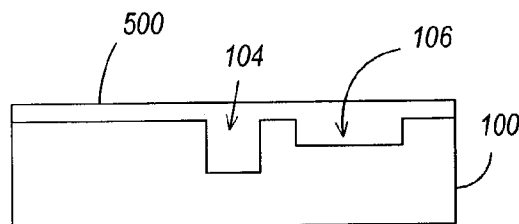


FIG. 6

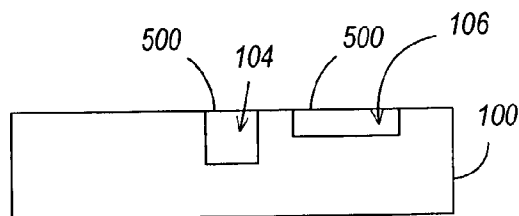


FIG. 7

FIG. 8

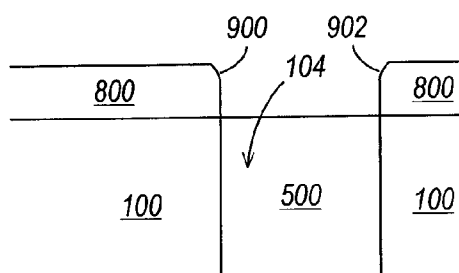
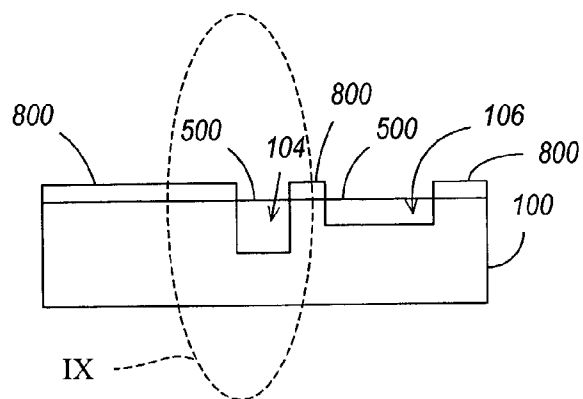


FIG. 9

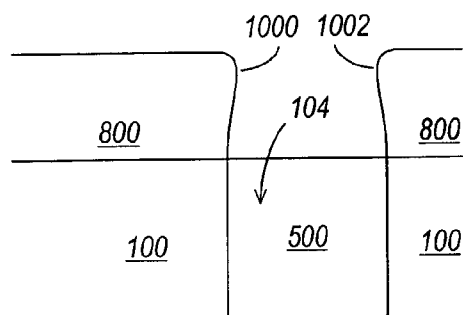


FIG. 10

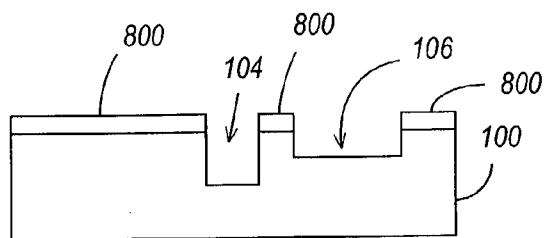


FIG. 11

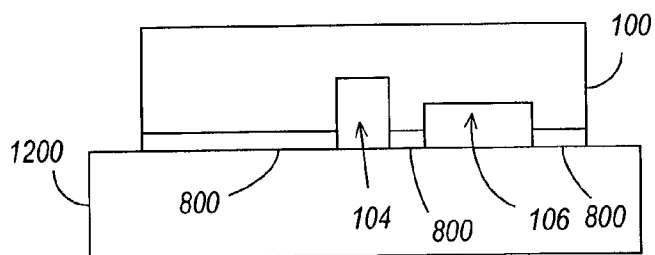


FIG. 12

FIG. 13

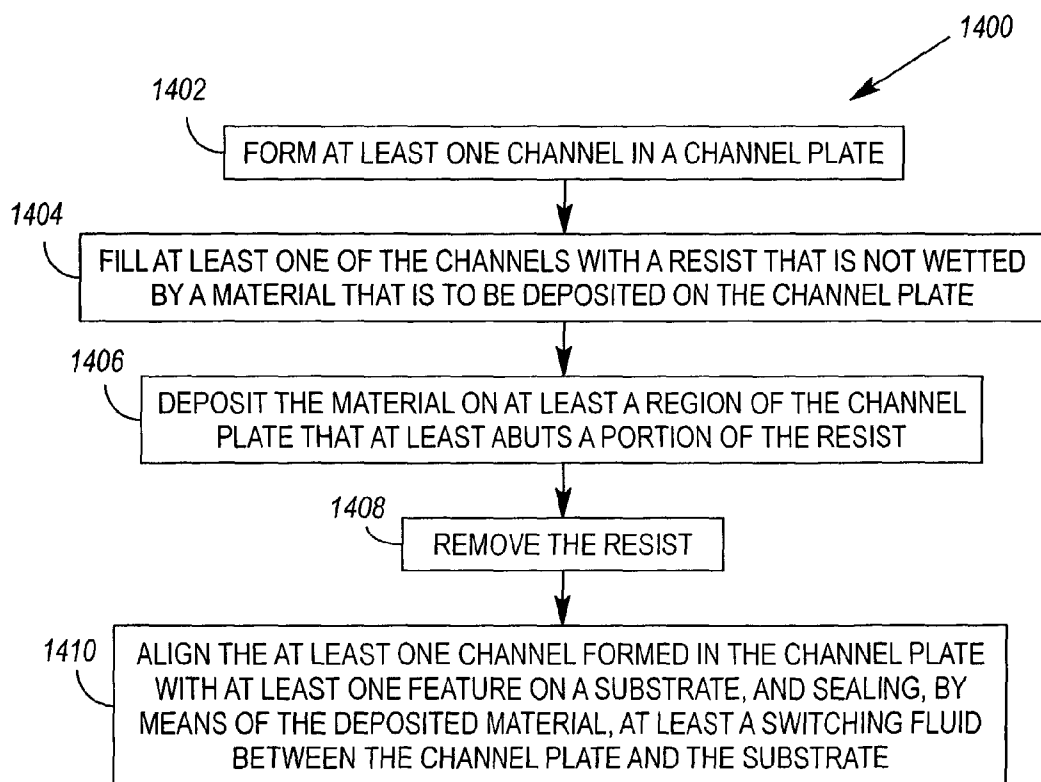
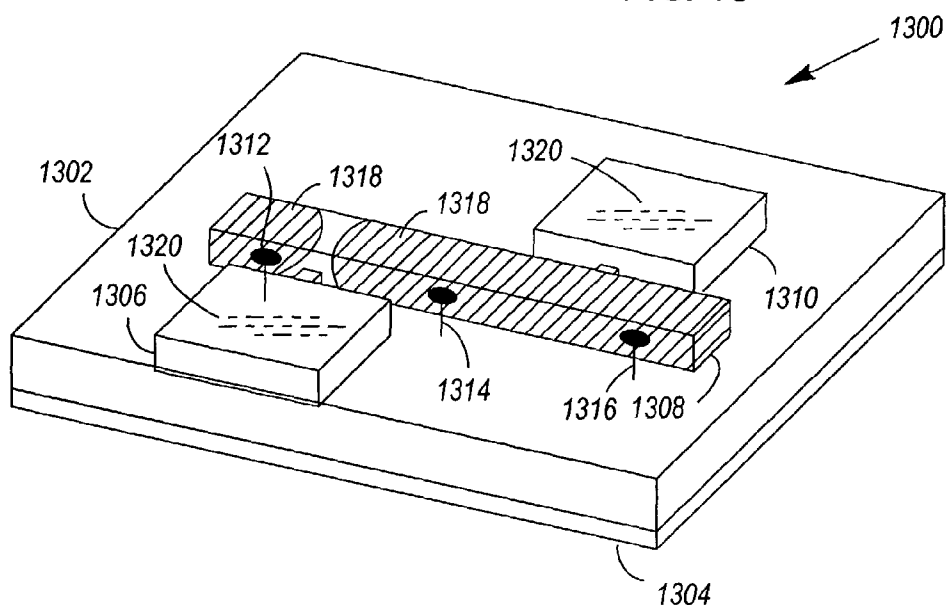


FIG. 14

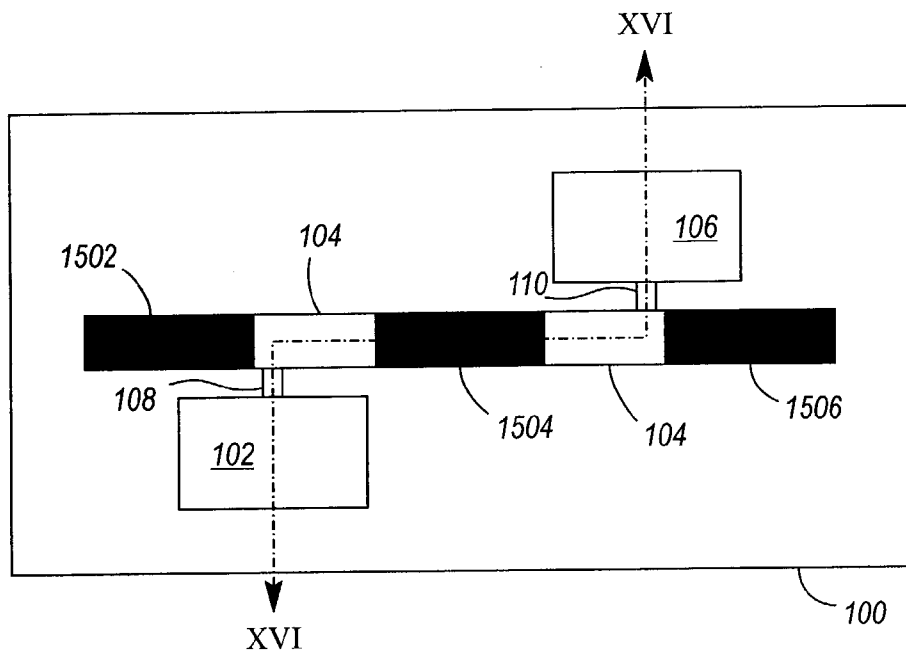


FIG. 15

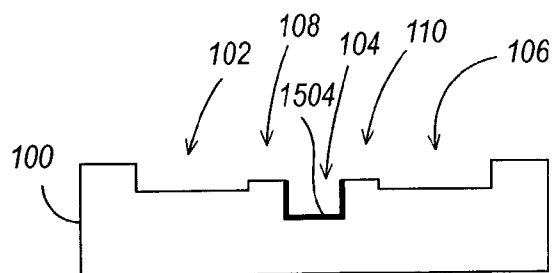


FIG. 16

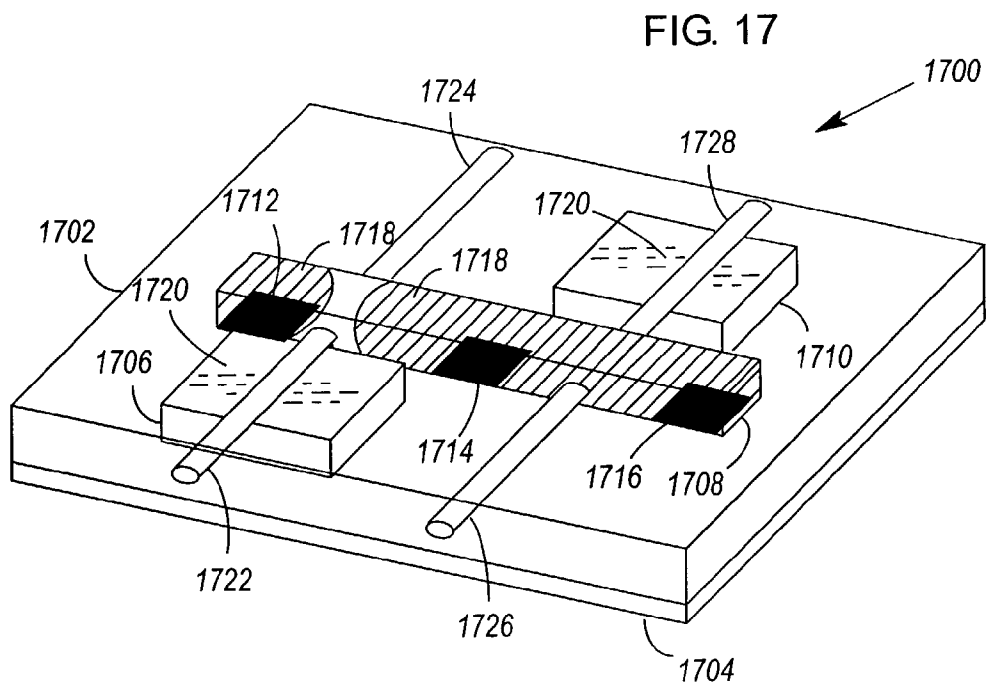


FIG. 17

METHOD FOR REGISTERING A DEPOSITED MATERIAL WITH CHANNEL PLATE CHANNELS, AND SWITCH PRODUCED USING SAME

BACKGROUND

[0001] Fluid-based switches such as liquid metal micro switches (LIMMS) are disclosed in the following patent and patent applications (the teachings of which are hereby incorporated by reference): U.S. Pat. No. 6,323,447 of Kondoh et al. entitled "Electrical Contact Breaker Switch, Integrated Electrical Contact Breaker Switch, and Electrical Contact Switching Method"; U.S. patent application of Marvin Glenn Wong entitled "A Piezoelectrically Actuated Liquid Metal Switch" (Ser. No. 10/137,691, filed May 2, 2002); and U.S. patent application of Marvin Glenn Wong entitled "Laser Cut Channel Plate for a Switch" (Ser. No. 10/317,932, filed Dec. 12, 2002).

[0002] One way to manufacture the switches disclosed in the above-referenced patent and patent applications is to 1) deposit an adhesive on a channel plate, and then 2) seal the desired combination of switching fluid(s), actuating fluid(s) and/or other switch components between the channel plate and a substrate.

[0003] When depositing the adhesive on the channel plate, it is typically desirable to "register" the adhesive with the channels of the channel plate. That is, it is desirable to deposit the adhesive on the channel plate so that it extends precisely up to, but not into, the channels of the channel plate. In this manner, the adhesive does not contribute to increasing or decreasing the volumes of cavities that are defined by the channels when the channel plate is sealed to the substrate.

SUMMARY OF THE INVENTION

[0004] One aspect of the invention is embodied in a method for depositing material on a channel plate such that the material is registered to one or more channels formed in the channel plate. The method comprises 1) filling at least one of the channels with a resist that is not wetted by the material, 2) depositing the material on at least a region of the channel plate that at least abuts a portion of the resist, and then 3) removing the resist.

[0005] Another aspect of the invention is embodied in a switch produced by 1) forming at least one channel in a channel plate, 2) filling at least one of the channels with a resist that is not wetted by a material that is to be applied to the channel plate, 3) depositing the material on at least a region of the channel plate that at least abuts a portion of the resist, 4) removing the resist, and 5) aligning the at least one channel formed in the channel plate with at least one feature on a substrate, and sealing, by means of the deposited material, at least a switching fluid between the channel plate and the substrate.

[0006] Other embodiments of the invention are also disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Illustrative embodiments of the invention are illustrated in the drawings, in which:

[0008] FIG. 1 illustrates an exemplary plan view of a channel plate for a switch;

[0009] FIG. 2 illustrates a first cross-section of the FIG. 1 channel plate;

[0010] FIG. 3 illustrates a second cross-section of the FIG. 1 channel plate;

[0011] FIG. 4 illustrates a method for depositing material on a channel plate such that the material is registered to one or more channels formed in the FIG. 1 channel plate;

[0012] FIGS. 5 & 6 illustrate how channels of the FIG. 1 channel plate may be filled with a resist;

[0013] FIG. 7 illustrates the channel plate of FIG. 5 or 6, after abrasion;

[0014] FIG. 8 illustrates the deposition of a material on the FIG. 1 channel plate while the channels of the channel plate are filled with a resist;

[0015] FIG. 9 illustrates the rounding of deposited material corners at the edges of a channel plate channel filled with resist;

[0016] FIG. 10 illustrates the leaning of deposited material edges at the edges of a channel plate channel filled with resist;

[0017] FIG. 11 illustrates the channel plate cross-section shown in FIG. 8, after the resist has been removed from the channel plate's channels;

[0018] FIG. 12 illustrates how the FIG. 1 channel plate may be sealed to a substrate;

[0019] FIG. 13 illustrates a first exemplary embodiment of a switch;

[0020] FIG. 14 illustrates an exemplary method for producing the switch illustrated in FIG. 13;

[0021] FIGS. 15 & 16 illustrate the metallization of portions of the FIG. 1 channel plate; and

[0022] FIG. 17 illustrates a second exemplary embodiment of a switch.

DETAILED DESCRIPTION OF THE INVENTION

[0023] When depositing material on a channel plate, it is sometimes desirable to register the material with one or more channels that are formed in the channel plate. That is, it is sometimes desirable to deposit material on a channel plate such that it extends precisely up to, but not into, the channels of the channel plate.

[0024] Fluid-based switches represent one application in which channel registration of a material is desirable. For example, during the manufacture of a switch in accordance with the patent and patent applications disclosed in the Background section of this disclosure, an adhesive may be applied to a channel plate for the purpose of sealing the channel plate to a substrate. Between the channel plate and substrate are sealed a combination of switching fluid(s), actuating fluid(s) and/or other switch components. When depositing the adhesive on the channel plate, it is typically desirable to register the adhesive with the channels of the channel plate so that the adhesive does not increase or decrease the volumes of cavities that are defined by the channels when the channel plate is sealed to the substrate.

[0025] One way to register an adhesive with the channels of a channel plate is to deposit a layer of adhesive on the channel plate, partially cure it, deposit a layer of photoresist on top of the adhesive, photodefine the photoresist layer, and then sandblast the adhesive from the channel plate's channels. However, disadvantages of this process include 1) relatively large tolerances in adhesive channel registration, as well as 2) rough channel surfaces as a result of the sandblasting. The process also places limits on the types of substrates that may be used for the channel plate, as well as the geometries of channel structures that can be accommodated.

[0026] The inventors have therefore devised new methods for depositing material on a channel plate, as well as new switches that are produced in accordance with the methods. The new methods provide better registration of deposited materials to the channel or channels that have been formed in the channel plate.

[0027] FIGS. 1-3 illustrate a first exemplary embodiment of a channel plate 100. FIG. 1 illustrates a plan view of the channel plate 100, while FIGS. 2 & 3 illustrate two exemplary cross-sections of the channel plate 100. Such a channel plate might be used, for example, in a fluid-based switch such as a LIMMS. By way of example, the channel plate 100 is shown to comprise five different channels 102, 104, 106, 108, 110 of varying depths. However, it is envisioned that more or fewer channels may be formed in a channel plate, depending on the configuration of the switch in which the channel plate is to be used. The base material for the channel plate 100 may be glass, ceramic, metal or polymer, to name a few. Depending on the base material used and the channel tolerances desired, channels may be machined, injection molded, press molded, slump molded, etched, laser cut, ultrasonically milled, laminated, stamped or otherwise formed in a channel plate 100.

[0028] For the purpose of this description, "channel" is defined to be any sort of groove, trough, pit or other feature that creates a recess in a channel plate that extends below the uppermost surface of the channel plate.

[0029] In accordance with the invention, FIG. 4 illustrates a method 400 for depositing material on a channel plate 100 so that the deposited material is registered to one or more channels 102-110 formed in the channel plate 100. The method 400 comprises filling 402 at least one of the channel plate's channels 102-110 with a resist that is not wetted by the material that is to be deposited on the channel plate 100. Although it is envisioned that all of a channel plate's channels 102-110 will typically be filled with the resist, there may be applications in which it might be desirable to fill or coat some of a channel plate's channels with a deposited material. In these applications, the channels that are to be filled or coated with the deposited material are not filled with the resist.

[0030] Channels 104, 106 may be filled with resist 500 as shown in FIG. 5 or 6, for example. In FIG. 5, a resist 500 is applied only to a channel plate's channels 104, 106. Alternatively, and as shown in FIG. 6, a resist 500 may be applied to an entire surface of a channel plate 100 such that it extends beyond the boundaries of a channel plate's channels 104, 106. Although application of a resist 500 as shown in FIG. 6 requires that portions of the resist 500 that fall outside of the channel plate's channels 104, 106 be

removed prior to the next step of the FIG. 4 method, application of a resist 500 as shown in FIG. 6 may be easier and quicker than application of a resist 500 as shown in FIG. 5.

[0031] Regardless of how a resist 500 is applied to a channel plate 100, it may be desirable to abrade the channel plate to make the resist 500 planar with the surface of the channel plate 100, or to better define transitions between the resist 500 and the edges of channels 104, 106 that are filled with the resist 500. Following abrasion, the channel plates 100 with resist 500 shown in FIGS. 5 and 6 may appear as illustrated in FIG. 7.

[0032] By way of example, a channel plate 100 may be abraded by means of chemical mechanical planarization, or grinding and polishing.

[0033] Although a channel plate 100 may be abraded solely for the purpose of removing excess resist 500, a channel plate 100 may also be abraded for the purpose of flattening the surface or surfaces of the channel plate bearing resist-filled channels 104, 106. If the material to be deposited on a channel plate 100 is an adhesive or gasket material, flattening the channel plate 100 may help the channel plate 100 achieve a better bond to (or fit with) a part to which it is later mated.

[0034] After filling one or more channels 104, 106 with a resist 500, a desired material 800 is deposited 404 (FIG. 4) on at least a region of the channel plate 100 that at least abuts a portion of the resist 500 (see FIG. 8). In other words, the material 800 need not be deposited over the entirety of a channel plate's surface, nor need the material 800 be deposited over a region of the channel plate 100 encompassing the entirety of a resist filled channel 104. Thus, for example, the material 800 may be deposited over a region 112 encompassing one end of a channel 104 that is filled with resist 500 (see FIG. 1), or the material 800 may be deposited primarily on one side 114, 116 of a channel 104 that is filled with resist 500. Alternately, the material 800 may be deposited over the entirety of one or more of a channel plate's surfaces.

[0035] By way of example, a material layer 800 may be deposited on a channel plate 100 by means of spin coating or spray coating. Since the resist 500 is selected so as not to be wetted by the material 800 that is deposited on the channel plate 100, and as a result of the deposited material's surface tension, the deposited material 800 will only extend up to the borders of the resist 500. Thus, if the resist 500 is precisely registered to the boundaries of a channel plate's channels 104, 106, so too will the deposited material 800 be registered to the boundaries of the channels 104, 106.

[0036] FIG. 9 illustrates how the corners 900, 902 of a deposited material 800 can "round" at the boundaries of a channel plate channel 104. This effect may be accentuated as the thickness of the deposited material 800 increases. If desired, the deposited material 800 may be abraded to remove that portion of the material where rounding is present.

[0037] FIG. 10 illustrates a possibly undesirable effect of depositing too thick of a material layer 800 on a channel plate 100. As shown in FIG. 10, a layer 800 that is too thick may "lean" over a channel plate channel 104. Again, the deposited material 800 may be abraded to remove that

portion of the material that leans excessively. Alternately, a thinner layer of material **800** may be deposited on the channel plate **100**.

[0038] After the material **800** has been deposited, the resist **500** may be removed **406** (see FIG. 11). By way of example, the resist **500** may be removed using an etching or developing process. Depending on the nature of the deposited material **800**, and the process used to remove the resist **500**, it may be necessary to cure the deposited material **800** prior to removing the resist **500**. The curing may be achieved by exposing the deposited material **800** to ambient conditions for a period of time, by heating the deposited material **800**, by submersing the deposited material **800** in an appropriate solution, or by other means. If necessary, the deposited material **800** may also be cured (or cured further) after the resist **500** is removed.

[0039] If desired, the channel plate **100**, with deposited material **800** thereon, may be mated to another part (e.g., in the case of a fluid-based switch wherein the deposited material **800** is an adhesive or gasket, the part to which the channel plate **100** is mated may be a switch substrate **1200** (FIG. 12)).

[0040] Given that fluid-based switch manufacture is one potential and intended application for the FIG. 4 method, some exemplary fluid-based switches to which the FIG. 4 method can be applied will now be described.

[0041] FIG. 13 illustrates a first exemplary embodiment of a switch **1300**. The switch **1300** comprises a channel plate **1302** defining at least a portion of a number of cavities **1306**, **1308**, **1310**. The remaining portions of the cavities **1306**-**1310**, if any, may be defined by a substrate **1304** to which the channel plate **1302** is sealed. Exposed within one or more of the cavities are a plurality of electrodes **1312**, **1314**, **1316**. A switching fluid **1318** (e.g., a conductive liquid metal such as mercury) held within one or more of the cavities serves to open and close at least a pair of the plurality of electrodes **1312**-**1316** in response to forces that are applied to the switching fluid **1318**. An actuating fluid **1320** (e.g., an inert gas or liquid) held within one or more of the cavities serves to apply the forces to the switching fluid **1318**.

[0042] In one embodiment of the switch **1300**, the forces applied to the switching fluid **1318** result from pressure changes in the actuating fluid **1320**. The pressure changes in the actuating fluid **1320** impart pressure changes to the switching fluid **1318**, and thereby cause the switching fluid **1318** to change form, move, part, etc. In FIG. 13, the pressure of the actuating fluid **1320** held in cavity **1306** applies a force to part the switching fluid **1318** as illustrated. In this state, the rightmost pair of electrodes **1314**, **1316** of the switch **1300** are coupled to one another. If the pressure of the actuating fluid **1320** held in cavity **1306** is relieved, and the pressure of the actuating fluid **1320** held in cavity **1310** is increased, the switching fluid **1318** can be forced to part and merge so that electrodes **1314** and **1316** are decoupled and electrodes **1312** and **1314** are coupled.

[0043] By way of example, pressure changes in the actuating fluid **1320** may be achieved by means of heating the actuating fluid **1320**, or by means of piezoelectric pumping. The former is described in U.S. Pat. No. 6,323,447 of Kondoh et al. entitled "Electrical Contact Breaker Switch, Integrated Electrical Contact Breaker Switch, and Electrical

Contact Switching Method". The latter is described in U.S. patent application Ser. No. 10/137,691 of Marvin Glenn Wong filed May 2, 2002 and entitled "A Piezoelectrically Actuated Liquid Metal Switch". Although the above referenced patent and patent application disclose the movement of a switching fluid by means of dual push/pull actuating fluid cavities, a single push/pull actuating fluid cavity might suffice if significant enough push/pull pressure changes could be imparted to a switching fluid from such a cavity. In such an arrangement, the channel plate for the switch could be constructed similarly to the channel plate **100** disclosed herein.

[0044] The channel plate **1302** of the switch **1300** may have a plurality of channels **102**-**110** formed therein, as illustrated in FIGS. 1-3. In one embodiment of the switch **1300**, the first channel **104** in the channel plate **100** (or **1302**) defines at least a portion of the one or more cavities **1308** that hold the switching fluid **1318**. By way of example, this switching fluid channel **104** may have a width of about 200 microns, a length of about 2600 microns, and a depth of about 200 microns.

[0045] A second channel (or channels **102**, **106**) may be formed in the channel plate **100** (or **1302**) so as to define at least a portion of the one or more cavities **1306**, **1310** that hold the actuating fluid **1320**. By way of example, these actuating fluid channels **102**, **106** may each have a width of about 350 microns, a length of about 1400 microns, and a depth of about 300 microns.

[0046] A third channel (or channels **108**, **110**) may be formed in the channel plate **100** (or **1302**) so as to define at least a portion of one or more cavities that connect the cavities **1306**-**1310** holding the switching and actuating fluids **1318**, **1320**. By way of example, the channels **108**, **110** that connect the actuating fluid channels **102**, **106** to the switching fluid channel **104** may each have a width of about 100 microns, a length of about 600 microns, and a depth of about 130 microns.

[0047] An exemplary method **1400** for producing the switch **1300** illustrated in FIG. 13 is illustrated in FIG. 14. The method **1400** commences with the formation **1402** of at least one channel **102**-**110** in a channel plate **100** (or **1302**). At least one of the channels **104** is then filled **1404** with a resist **500** that is not wetted by a material **800** that is to be deposited on the channel plate **100**. Thereafter, the material **800** is deposited **1406** on at least a region of the channel plate **100** that at least abuts a portion of the resist **500**. The material **800** may be applied in a variety of ways that include, for example, spin coating and spray coating.

[0048] After depositing the material **800**, the resist **500** is removed **1408**. Optionally, the deposited material **800** may be cured prior to removing the resist **500**. Finally, the at least one channel **102**-**110** formed in the channel plate **100** (or **1302**) is aligned with at least one feature on a substrate **1304**, and at least a switching fluid **1318** is sealed **1410** between the channel plate **1302** and the substrate **1304**, by means of the deposited material **800**. As taught in FIG. 13, an actuating fluid **1320** may also be sealed between the channel plate **1302** and substrate **1304**.

[0049] The material **800** deposited on the channel plate **1302** may be, for example, an adhesive or gasket material. One suitable adhesive is Cytop™ (manufactured by Asahi

Glass Co., Ltd. of Tokyo, Japan). Cytop™ comes with two different adhesion promoter packages, depending on the application. When a channel plate **100** has an inorganic composition, Cytop™'s inorganic adhesion promoters should be used and an organic resist **500** should be used. Similarly, when a channel plate **100** has an organic composition, Cytop™'s organic adhesion promoters should be used, and an inorganic resist **500** should be used (including, possibly, an inorganic resist such as a thin sputtered-on coating of metal or glass).

[0050] Optionally, and as illustrated in FIGS. 15 & 16, portions of a channel plate **100** (or **1302**) may be metallized (e.g., via sputtering or evaporating through a shadow mask, or via etching through a photoresist) for the purpose of creating "seal belts" **1502, 1504, 1506**. Seal belts **1502-1506** may be created before or after the deposition of adhesive or gasket material on a channel plate **100**. The creation of seal belts **1502-1506** within a switching fluid channel **104** provides additional surface areas to which a switching fluid may wet. This not only helps in latching the various states that a switching fluid can assume, but also helps to create a sealed chamber from which the switching fluid cannot escape, and within which the switching fluid may be more easily pumped (i.e., during switch state changes).

[0051] Additional details concerning the construction and operation of a switch such as that which is illustrated in FIG. 13 may be found in the afore-mentioned patent of Kondoh et al. and patent application of Marvin Wong.

[0052] FIG. 17 illustrates a second exemplary embodiment of a switch **1700**. The switch **1700** comprises a channel plate **1702** defining at least a portion of a number of cavities **1706, 1708, 1710**. The remaining portions of the cavities **1706-1710**, if any, may be defined by a substrate **1704** to which the channel plate **1702** is sealed. Exposed within one or more of the cavities are a plurality of wettable pads **1712-1716**. A switching fluid **1718** (e.g., a liquid metal such as mercury) is wettable to the pads **1712-1716** and is held within one or more of the cavities. The switching fluid **1718** serves to open and block light paths **1722/1724, 1726/1728** through one or more of the cavities, in response to forces that are applied to the switching fluid **1718**. By way of example, the light paths may be defined by waveguides **1722-1728** that are aligned with translucent windows in the cavity **1708** holding the switching fluid. Blocking of the light paths **1722/1724, 1726/1728** may be achieved by virtue of the switching fluid **1718** being opaque. An actuating fluid **1720** (e.g., an inert gas or liquid) held within one or more of the cavities serves to apply the forces to the switching fluid **1718**.

[0053] Forces may be applied to the switching and actuating fluids **1718, 1720** in the same manner that they are applied to the switching and actuating fluids **1718, 1720** in FIG. 13.

[0054] The channel plate **1702** of the switch **1700** may have a plurality of channels **102-110** formed therein, as illustrated in FIGS. 1-3. In one embodiment of the switch **1700**, the first channel **104** in the channel plate **100** (or **1702**) defines at least a portion of the one or more cavities **1708** that hold the switching fluid **1718**.

[0055] A second channel (or channels **102, 106**) may be formed in the channel plate **100** (or **1702**) so as to define at

least a portion of the one or more cavities **1706, 1710** that hold the actuating fluid **1720**.

[0056] A third channel (or channels **108, 110**) may be formed in the channel plate **100** (or **1702**) so as to define at least a portion of one or more cavities that connect the cavities **1706-1710** holding the switching and actuating fluids **1718, 1720**.

[0057] Additional details concerning the construction and operation of a switch such as that which is illustrated in FIG. 17 may be found in the afore-mentioned patent of Kondoh et al. and patent application of Marvin Wong. Furthermore, an adhesive or gasket layer, as well as seal belts, may be applied to the switch's channel plate **1702** as described supra, and as shown in FIGS. 14-16.

[0058] The use of channel plates is not limited to the switches **1300, 1700** disclosed in FIGS. 13 & 17 and may be undertaken with other forms of switches that comprise, for example, 1) a channel plate defining at least a portion of a number of cavities, a first cavity of which is defined by an ultrasonically milled channel in the channel plate, and 2) a switching fluid, held within one or more of the cavities, that is movable between at least first and second switch states in response to forces that are applied to the switching fluid.

[0059] While illustrative and presently preferred embodiments of the invention have been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed, and that the appended claims are intended to be construed to include such variations, except as limited by the prior art.

What is claimed is:

1. A switch, produced by:
 - a) forming at least one channel in a channel plate;
 - b) filling at least one of the channels with a resist that is not wetted by a material that is to be deposited on the channel plate;
 - c) depositing the material on at least a region of the channel plate that at least abuts a portion of the resist;
 - d) removing the resist; and
 - e) aligning the at least one channel formed in the channel plate with at least one feature on a substrate, and sealing, by means of the deposited material, at least a switching fluid between the channel plate and the substrate.
2. The switch of claim 1, further comprising, curing the deposited material prior to removing the resist.
3. The switch of claim 1, wherein the deposited material is an adhesive.
4. The switch of claim 1, wherein the deposited material is a gasket material.
5. The switch of claim 1, wherein the material is deposited by means of spin coating.
6. The switch of claim 1, wherein the material is deposited by means of spray coating.
7. The switch of claim 1, wherein:
 - a) a first channel formed in the channel plate is a channel for holding the switching fluid; and
 - b) the channel for holding the switching fluid is filled with the resist.

8. The switch of claim 7, wherein:

- a) a second channel formed in the channel plate is an actuating fluid channel;
- b) the actuating fluid channel is filled with the resist; and
- c) the method further comprises sealing an actuating fluid between the channel plate and the substrate.

9. The switch of claim 1, wherein:

- a) the at least one channel formed in the channel plate comprises a channel for holding the switching fluid, a pair of channels for holding an actuating fluid, and a pair of channels connecting corresponding ones of the channels holding the actuating fluid to the channel holding the switching fluid; and

- b) all of the channels are filled with the resist.

10. A method for depositing material on a channel plate such that the material is registered to one or more channels formed in the channel plate, comprising:

- a) filling at least one of the channels with a resist that is not wetted by the material;
- b) depositing the material on at least a region of the channel plate that at least abuts a portion of the resist; and
- c) removing the resist.

11. The method of claim 10, wherein the material is an adhesive.

12. The method of claim 11, further comprising, curing the adhesive prior to removing the resist.

13. The method of claim 11, wherein the adhesive is Cytop.

14. The method of claim 10, wherein the material is applied by means of spin coating.

15. The method of claim 10, wherein the material is applied by means of spray coating.

16. The method of claim 10, wherein the resist is removed by means of etching.

17. The method of claim 10, wherein the resist is removed by means of developing.

18. The method of claim 10, further comprising, after filling the at least one channel with the resist, abrading the channel plate to better define transitions between the resist and edges of channels that are filled with the resist.

19. The method of claim 18, wherein said abrading is accomplished by means of chemical mechanical planarization.

20. The method of claim 18, wherein said abrading is accomplished by means of polishing.

21. The method of claim 10, further comprising, after filling the at least one channel with the resist, flattening a surface of the channel plate bearing resist-filled channels.

* * * * *